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MCDONNELL DOUGLAS TECHNICAL SERVICES CO.
HOUSTON ASTRONAUTICS DIVISION

NASA CR-

150969

SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT

DESIGN NOTE NO. 1.4-7-14

DISPERSION ANALYSIS TECHNIQUES
WITHIN THE SPACE VEHICLE DYNAMICS
SIMULATION PROGRAM

MISSION PLANNING, MISSION ANALYSIS AND SOFTWARE FORMULATION

29 August 1975

This Design Note is Submitted to NASA Under Task Order
No. D0302, Task Assignment 1.4-7-F, Contract NAS 9-13970.

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N76-32215

Unclas
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(NASA-CR-150969) DISPERSION ANALYSIS
TECHNIQUES WITHIN THE SPACE VEHICLE DYNAMICS
SIMULATION PROGRAM (McDonnell-Douglas
Technical Services) 9 p HC \$3.50 CSC1 22A



1.0 INTRODUCTION

This paper presents an evaluation of the Space Vehicle Dynamics Simulation (SVDS) program as a dispersion analysis tool. This evaluation is a continuation of an analysis reported in Reference 1. Reference 1 describes navigation results and briefly reports on the Linear Error Analysis (LEA) post processor. This study examines the LEA in detail and considers simulation techniques relative to conducting a dispersion analysis using SVDS.

The LEA processor is a tool for correlating trajectory dispersion data developed by simulating 3 σ uncertainties as single error source cases. The processor combines trajectory and performance deviations by a root-sum-square (RSS) process and develops a covariance matrix for the deviations. Results are used in dispersion analyses for the baseline reference and orbiter flight test missions as conducted by the Guidance and Dynamics Branch (GDB).

As a part of this study, LEA results were verified as follows:

- a. Hand calculating the RSS data and the elements of the covariance matrix for comparison with the LEA processor computed data.
- b. Comparing results with previous error analyses generated by the GDB (References 2 and 3).

A program modification to the LEA was used to correct this in the study. Permanent modification to LEA should be made.

Comparison of the corrected altitude rate calculations of this study and data from References 2 and 3 indicate differences in the deviations for uncertainties in solid rocket booster (SRB) thrust, orbiter thrust, and orbiter specific impulse (ISP). The differences were found to result from the accuracy in guidance cutoff of the flight-path angle. For example, altitude rate deviations for orbiter ISP uncertainty is -2.29 ft/sec in this study, and -1.03 ft/sec in Reference 2. The 1.26 ft/sec difference in the deviations is indicative of a flight-path angle difference of .0023 degrees. Comparison of the flight-path angle deviations from the two studies shows that the actual deviation is .0029 degrees. Similar results were observed for the other error sources for which altitude rate deviations exist. Hence, the differences are a result of the small differences in the accuracy of guidance cutoff conditions.

Results obtained from the LEA processor are to be documented as part of the dispersion analyses for the baseline reference missions. For documentation purposes some changes to the LEA output format are desirable. The RSS data has been expanded to include more trajectory parameters and the output has been reformatted to be consistent with dispersion analysis documentation requirements.

The simulations developed in this study are for baseline reference mission 3A. The LEA comparisons and verification are made at main engine cutoff (MECO).

2.0 DISCUSSION

2.1 LEA Processor

The LEA processor performs the following two functions:

1) Combines trajectory deviations by a RSS process and 2) develops a covariance matrix for the deviations. Covariance matrix data (state vector deviations) are presented in a local horizontal coordinate system (LHS). (See Reference 1). RSS data should include deviations in altitude, down range and cross range position, and cross range rate presented in the LHS. Speed, flight-path angle, altitude rate, time and weight are also included in the RSS data.

Comparison of the data generated in this study to Reference 2 and 3 data indicates that the processor is functioning properly except for altitude rate calculations in the RSS data. An altitude rate (ALT RATE) deviation is defined as:

$$\text{ALT RATE} = \text{Velocity}_{\text{actual}} * \text{Sine} (\text{Flight-path angle}_{\text{actual}}) - \text{Velocity}_{\text{nominal}} * \text{Sine} (\text{Flight-path angle}_{\text{nominal}})$$

where "actual" refers to the actual integrated state of a perturbed case and "nominal" is the integrated state of the nominal case. However, in its RSS data, the processor uses the vertical component of the velocity deviations as rotated into the LHS (U-dot) as altitude rate. U-dot and altitude rate are comparable only if there is no radius vector dispersion between the nominal and actual states. It is requested that altitude rate (as described above) should be included in the RSS data

and velocity deviations rotated into the LHS (U-dot) be included in the covariance matrix of the LEA processor.

In addition, the following format changes need to be made to the processor output:

- a. Specify the event or time slice for which covariance matrix is output.
- b. Output the lower half of the covariance matrix.
- c. Print nominal time and weight for each event or time slice.

A SVDS Work Request (Reference 6) has been submitted for the indicated changes to the processor.

2.2 Vehicle Attitude History During First Stage Flight

During this study, the previously used practice of determining first stage attitude was initially used. That is, first stage flight is initialized by a six-second vertical rise for tower clearance. At tower clearance, a ten-second pitchover maneuver begins. The maneuver is executed at a constant body pitch rate. At sixteen seconds from liftoff, a gravity turn maneuver is begun. This maneuver (beginning at sixteen seconds and terminating at SRB separation), consists of determining the vehicle attitude required to ensure zero angle of attack flight at each integration cycle.

In previous dispersion analyses conducted using three degree of freedom flight simulations, the pitchover maneuver is optimized for the nominal vehicle and this pitch rate is used for all perturbation cases. However, severe performance penalties are

realized when this technique is used when simulating vehicle performance uncertainties. A more acceptable technique for simulating first stage attitude control is using vehicle attitude of the nominal trajectory (as a function of relative velocity) as the first stage guidance commands of the perturbation cases. This technique ensures that the perturbation cases follow the near optimum attitude/velocity history of the nominal trajectory. It should be noted that first stage steering defined by attitude as a function of relative velocity is the current flight software technique being baselined for issuing steering commands during first stage flight.

When attempting to use attitude as a function of relative velocity in the SVDS program, it was discovered that the evaluation of relative velocity magnitude is one computation cycle behind in the steering routines. A modification has been made to SVDS to correct this problem. A discrepancy report (Reference 4) has been submitted in order that SVDS may be permanently modified as indicated.

2.3 SRB Thrust Perturbation (Web Action Time)

Current terminology used when discussing propulsion system uncertainties includes such items as specific impulse uncertainty and thrust uncertainty. However, Marshall Space Flight Center (MSFC) now indicates that they no longer consider thrust uncertainty for the SRB's (Reference 5). Instead of thrust uncertainty, the reference considers "web action time" as a performance uncertainty for the SRB's. Web action time includes

SRB thrust and cutoff time effects. This study adopted the SRB perturbation techniques described in Reference 5. The following observations should be noted when using the web action time equations of the reference:

- a. The percent variation used for web action time does not result in the same variation in SRB thrust. For example, a +4.33% action time uncertainty results in a -4.15% thrust reduction.
- b. A symmetric variation in web action time (e.g., $\pm 4.33\%$) does not result in a symmetric thrust variation (-4.15%, +4.53%).

2.4 SVDS Phase Termination at Entry Interface

Previous GDB dispersion analyses for ascent performance simulations have considered the time interval from liftoff to entry interface. In these studies, entry interface conditions were determined by a velocity versus flight-path angle line for a specific radius. The simulated entry interface conditions were sensed by the radius vector magnitude. It should be noted that the guidance simulation is being driven by the navigated state; i.e., the guidance attempts to drive the navigated state toward the input target conditions. However, in previous dispersion analyses, entry interface conditions were assumed to be achieved when the magnitude of the radius vector of the integrated (actual) state is equivalent to the magnitude of the target radius vector. The effect of this is the following:

- a. Neither the actual nor the navigated state achieve the target conditions at entry interface.
- b. Dispersion analysis results of platform uncertainty simulations (at entry interface) are erroneous since the actual state is always forced to the same cutoff condition (a specified radius magnitude).

During this study, entry interface conditions are assumed to be achieved when the magnitude of navigated state reaches the magnitude of the input target vector.

3.0 CONCLUSIONS

The LEA processor should be modified to output altitude rate as part of the RSS data. Output format changes need to be made for ease in documentation of dispersion analyses. These changes need to be made as permanent modifications to the SVDS program and the LEA processor.

In the future, evaluations of vehicle performance uncertainties should:

- a. Use first stage steering determined by the attitude/relative velocity history of a nominal trajectory.
- b. Web action time should replace SRB thrust as a simulated uncertainty.
- c. Entry interface conditions should be determined by the navigated state instead of the actual state.

REFERENCE:

1. Design Note No. 1.4-7-7, "Dispersion Analysis and Linear Error Analysis Capabilities of the Space Vehicle Dynamics Simulation Program," dated 12 May 1975.
2. JSC Internal Note No. 73-FM-47, "Space Shuttle System Baseline Reference Missions, Volume III - Mission 3A and Mission 3B, Revision 1," dated 7 May 1974.
3. NASA Memorandum FM73(74-146), "Error Analysis for Reference Mission 3A," dated 7 Aug 1974.
4. SVDS Discrepancy Report MDC-67, "Relative Velocity in GTURN," dated 24 July 1975.
5. Ron Toelle (MSFC), Sixth meeting of the Ascent Performance Panel, "Method of Simulating SRB Dispersions," 10-11 December 1974.
6. SVDS Work Request, "Recommended Changes for the LEA Processor," dated 20 Aug 1975.